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Treatment of Synthetic Wastewater in a Pre-Denitrification Biofilm Reactor Packed with Polyurethane Media

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Abstract

In the experiment, a pre-denitrification biofilm reactor with polyurethane as media was used to treat synthetic wastewater, and the influence of air-liquid ratio(A/L), hydraulic loading and reflux ratio on the performance of the reactor was investigated. The experimental results indicate that, when the influent concentration of COD was 270-300mg/L, NH_4^+-N was 33-35mg/L and TN was 35-40mg/L, under the operating condition of the air-liquid ratio being 8:1, the hydraulic loading being 0.96m/h(HRT of 1.5h), and reflux ratio being 150%, the removal efficiency of COD, NH_4^+-N and TN attained to 86%, 94% and 64%, respectively. The effluent quality satisfied the discharging standard of integrated wastewater of Liaoning (DB 21/1627-2008). In the pre-denitrification biofilm reactor, COD and TN removal was mainly realized in the anoxic zone, while NH_4^+-N removal was mainly achieved in the oxic zone. In order to guarantee the good quality of the effluent, the COD, NH_4^+-N and TN loading should be controlled below 6.42, 0.71 and 0.58kg/(m³·d), respectively, and the influent COD/TN ratio should be greater than 6.

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Keywords: A pre-denitrification biofilm reactor; synthetic wastewater; polyurethane; technical parameter

1. Introduction

With China's wastewater discharge standard getting increasingly stricter, some enterprises whose secondary effluents can't reach new discharge standard are facing the issue of reconstruction. Their effluent belongs to low concentration wastewater with a small quantity of carbon source and bad biodegradability. Therefore, it is necessary to find a new technology for advanced treatment of low concentration wastewater. In this paper, a combined biofilm reactor based on A/O and biofilm process was designed to remove both organic carbon and nitrogen of wastewater[1]. In biofilm reactor, the property of media directly affects the treatment effect and the investment cost[2]. In the experiment, a kind of polyurethane media, which had the characteristics of wear resistance, high specific surface and being suspended in water, was used as the biological media of the reactor to treat synthetic wastewater

which simulated low concentration wastewater. The effect of air-liquid ratio (A/L), hydraulic loading, the reactor height and reflux ratio on the removal performance of the reactor were investigated.

2. The experimental device and methods

A. The experimental device

As shown in figure 1, the experimental device is made from a PVC pipe with inner diameter of 150mm, cross-sectional area of 0.0177m² and effective volume of 26L. The reactor is composed of anoxic and oxic zone and the volume ratio anoxic zone to oxic zone is about 1:1. Sewage is injected into the bottom of reactor by metering pump and effluent is discharged from the top of reactor, air is diffused into the middle height of the reactor by an air compressor. To prevent the loss of media, a baffle with many small holes is put at the top of the oxic zone.

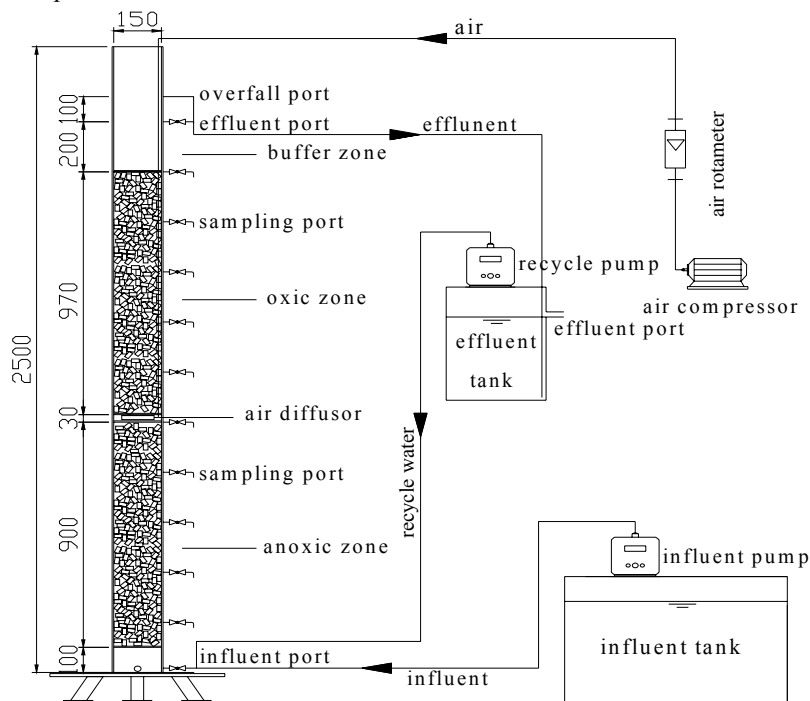


Figure 1. Schematic diagram of experimental device

B. Quality of the feed

During the whole experimental period, the pre- denitrification biofilm reactor was fed with artificial wastewater which was synthesized by C₆H₁₂O₆, NH₄Cl, KH₂PO₄, Na₂CO₃, etc. Wastewater characteristics are shown in Table 1.

Table 1. Wastewater characteristics of influent

Pollutant	COD(mg/L)	NH ₄ ⁺ -N(mg/L)	TN(mg/L)	pH
concentration	270-300	30-35	35-40	7-8

C. Analytical methods

The concentrations of COD, NH₄⁺-N and NO₃⁻-N were measured according to standard method[3]. TN was measured by micro TOC-TN.

Table 2. The effect of air-liquid ratio on removal performance

Air-liquid ratio	COD(mg/L)			NH ₄ ⁺ -N (mg/L)			TN(mg/L)		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
4: 1	287	86	70%	33.6	8.6	74%	33.7	18.4	45%
6: 1	290	57	80%	35.1	4.7	87%	36.2	15.2	58%
8: 1	281	38	86%	34.5	2.1	94%	35.6	12.9	64%
10: 1	279	32	89%	33.7	1.8	95%	32.9	14.8	55%
12: 1	295	35	88%	34.8	0.9	97%	35.8	16.7	53%

3. Experimental results and discussion

A. The bio-film formation

The bio-film reactor was inoculated with the activated sludge from an aeration basin of Chunliuhe Wastewater Treatment Plant, Dalian China. After inoculation, the reactor was first operated intermittently and then continuously, during the bio-film formation, hydraulic loading, air-liquid ratio and reflux ratio were gradually increased[4].

After two weeks, as shown in figure 2, the color of the packed media changed from black to flaxen and many microorganisms, such as vorticellidae, rotifers, etc. were observed on the surface of the media through microscopes, the concentration of COD, NH₄⁺-N and TN in the effluent reached to a steady state and bio-film formation was regarded successful.



Figure 2. The contrast diagram of bio-film formation

B. The effect of air-liquid ratio on removal performance

Air-liquid ratio is an important influence factor in pre-denitrification process. When the air-liquid ratio is too low, DO in oxic zone is insufficient, resulting in insufficient nitrification. When the air-liquid ratio is too high, DO in the recirculation water is high, denitrification will be affected greatly[5]. In order to achieve good effect of TN removal, suitable air-liquid ratio should be chosen. Under the experimental condition that reflux ratio is 150% and influent flow rate of raw wastewater was 17L/h, air influx rate was set at 0.07, 0.1, 0.14, 0.17 and 0.2 L m³/h, respectively, accordingly A/L ratio was of 4:1, 6:1, 8:1, 10:1 and 12:1, respectively. Time of each A/L ratio condition last two days and samples were collected and measured on the third day.

It can be observed from table 2 the removal of COD and NH₄⁺-N firstly increased and then flattened, but TN climbed up and then declined. Because in the low A/L, nitrification is not sufficient, pre-denitrification needed less carbon source, COD and NH₄⁺-N were mainly degraded in oxic zone, with A/L increasing, the removal of every index increased, when the air-liquid ratio is 8:1, there were sufficient DO in oxic zone for the occurrence of nitrification, COD was mainly used as the carbon sources of denitrification, each index reached Liaoning integrated wastewater discharge standard, As the air-liquid ratio continued to increase, dissolved oxygen in recycle water begin to increase, result in deterioration of denitrification, so the removal of TN declined greatly. The above experiment indicated that air-liquid ratio of 8:1 should be chosen as the optimum A/L.

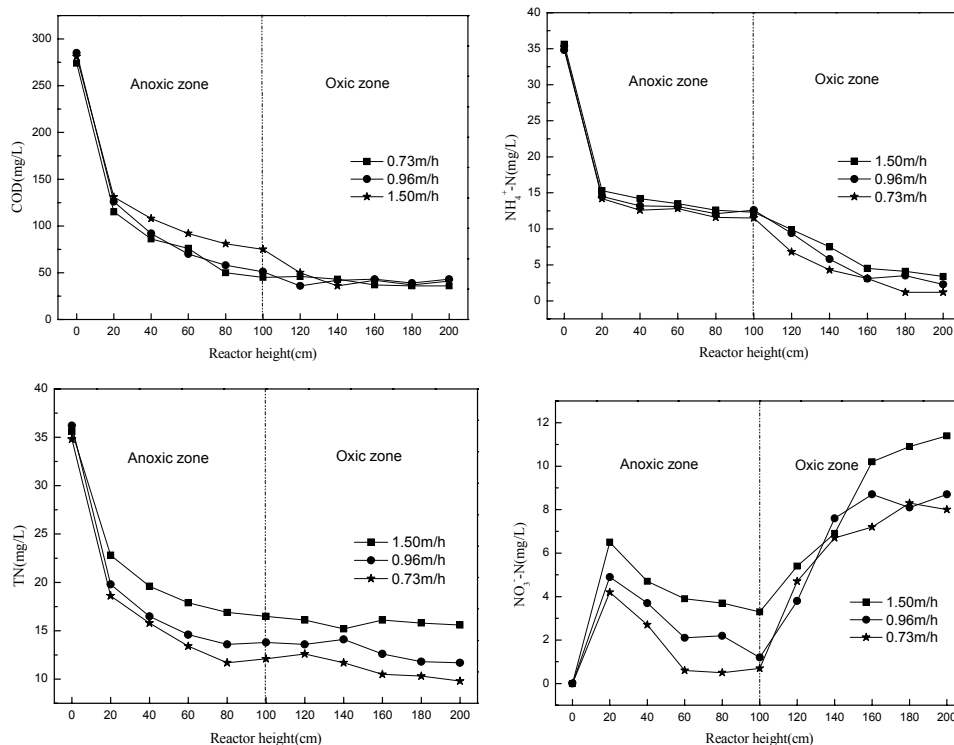


Figure 3. The effect of hydraulic loading and reactor height on removal performance

C. Effect of hydraulic loading on removal performance

Hydraulic loading is another important factor. On the one hand, hydraulic loading directly determine HRT of the reactor, further influence the size of volume, on the other hand, hydraulic loading directly affect the removal effect in biofilm process[6], so, choosing appropriate hydraulic loading is necessary. In the experiment, when the reflux ratio is 150%, A/L is 8:1, influent flow rate of raw wastewater was kept at 13, 17 and 26 L/h, respectively, and hydraulic loading was 0.73, 0.96, and 1.5m/h accordingly. Time of each hydraulic loading condition last two days and samples were collected and measured on the third day.

Figure 3 shows that when the hydraulic loading increased from 0.73m/h to 0.96m/h, the activity of microorganism is improved because of the increased scouring of padding, satisfied removal of COD, $\text{NH}_4^{+}\text{-N}$ and TN was achieved. When the hydraulic loading increased from 0.93m/h to 1.5m/h, the concentration of COD in anoxic zone rose from 51mg/L to 75mg/L, but COD was further degraded in oxic zone and effluent COD reached to 41mg/L; the increase of hydraulic loading result in the incomplete nitrification and $\text{NH}_4^{+}\text{-N}$ concentration increased with the increase of the hydraulic loading, TN concentration increased from 11.7mg/L to 15.6mg/L. Through the description of the figure 3, it can be concluded that hydraulic loading of 0.96m/h should be chosen as the optimum hydraulic loading, namely, the flow rate of 17L/h, HRT of 1.5h.

D. The effect of reactor height on removal performance

The species and quantity of microorganism in the reactor at different height was different[7]. When the operating parameters were as follows: reflux ratio of 150%, A/L of 8:1, HRT of 1.5h, concentrations of COD, $\text{NH}_4^{+}\text{-N}$, NO_3^{--}N and TN of the samples collected at different reactor height was measured to further study pollutants removal characteristics.

It can be observed from figure 3, the removal of COD was mainly realized in anoxic zone and the removal in oxic zone is stable. This is because the backflow and denitrification makes COD degrade rapidly. When the hydraulic loading is high, the removal of COD in anaerobic period begins to reduce, COD in oxic zone degrade further, thereby the effluent COD can achieve the desired treatment effect.

$\text{NH}_4^{+}\text{-N}$ in anoxic and oxic zone have very good removal efficiency, because, refluxing is primary cause in the decrease of the concentration of $\text{NH}_4^{+}\text{-N}$ in anoxic zone, while in oxic zone, nitrification is primary cause and $\text{NH}_4^{+}\text{-N}$ was turned into NO_3^{--}N , therefore, nitrification is the prerequisite of denitrification.

Similar with COD removal, TN removal was mainly realized in anoxic zone, in which NO_3^{--}N recirculated from oxic zone was denitrified utilizing influent organic as carbon source.

Table 3. The effect of recirculation on removal performance

Reflux ratio	COD(mg/L)			$\text{NH}_4^{+}\text{-N}$ (mg/L)			TN(mg/L)		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
100%	277	41	85%	34.7	1.7	95%	35.9	15.8	56%
150%	285	43	85%	34.8	2.3	93%	36.2	11.7	68%
200%	283	35	88%	35.6	0.8	98%	35.8	8.8	75%

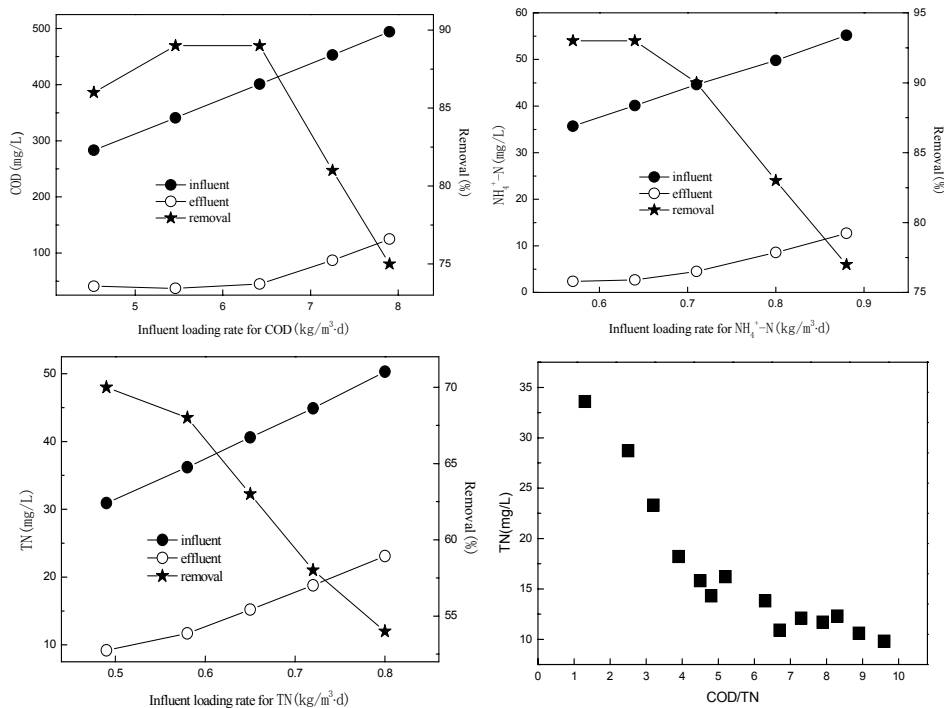


Figure 4. The effect of influent organic loading rates and COD/TN on removal performance

E. The effect of reflux ratio on on removal performance

Reflux ratio is an important factor which directly affects denitrification effect in pre-denitrification process [8]. When operation parameters were as follows: HRT of 1.5h, A/L of 8:1, reflux ratio of 100%, 150% and 200% were selected, respectively. Under every reflux ratio, the effect of reflux ratio on COD, NH₄⁺-N and TN of effluent were investigated. Time of each reflux ratio condition last two days and samples were collected and measured on the third day.

It can be observed from the table 3, when reflux ratio is 100%, the effluent concentration of COD, NH₄⁺-N and TN were 41, 1.7 and 15.8mg/L, respectively. When the reflux ratio increased from 100% to 200%, the removal of COD and NH₄⁺-N hardly changed, but the removal of TN increased obviously, effluent TN reached 8.8mg/L. Because dilution effect is more and more obvious with reflux ratio increasing, so electing reflux ratio of 150% is a better choice compared to other reflux ratio.

F. The effect of the organic loading of the influent and COD/TN on removal performance

Due to the large change of water quality in the actual situation, the effect of the organic loading of the influent on removal performance indicated the capacity of impact resistance of organic loading. When operation parameters were as follows: HRT of 1.5h, A/L of 8:1, Reflux ratio of 150%, by changing the concentrations of COD, NH₄⁺-N and TN, the effect of the organic loading of the influent and COD/TN on removal performance were investigated.

Figure 4 shows that influent loading rate for COD increased from 4.53 kg/(m³·d) to 6.42 kg/(m³·d);

influent loading rate for NH_4^+-N increased from $0.57\text{kg}/(\text{m}^3\cdot\text{d})$ to $0.71\text{kg}/(\text{m}^3\cdot\text{d})$. COD and NH_4^+-N of effluent can achieve better treatment efficiencies, the efficiency of COD and NH_4^+-N are relatively stable. When influent loading rate for COD and NH_4^+-N are greater than $6.42\text{kg}/(\text{m}^3\cdot\text{d})$ and $0.71\text{kg}/(\text{m}^3\cdot\text{d})$, respectively. The removal efficiency of COD and NH_4^+-N descended obviously. To ensure water quality of effluent, influent loading rate for COD and NH_4^+-N are less than $6.42\text{kg}/(\text{m}^3\cdot\text{d})$ and $0.71\text{kg}/(\text{m}^3\cdot\text{d})$, respectively.

The concentration of TN increased from $36.2\text{mg}/\text{L}$ to $40.6\text{mg}/\text{L}$, namely, influent loading rate for TN increased from $0.58\text{kg}/(\text{m}^3\cdot\text{d})$ to $0.65\text{kg}/(\text{m}^3\cdot\text{d})$, effluent TN don't achieve desired treatment effect. Thus it can be observed influent loading rate for TN affect greatly the removal effect of TN. So influent loading rate for TN should be less than $0.58\text{kg}/(\text{m}^3\cdot\text{d})$.

Carbon sources play an important role in the denitrification, the various organic in the wastewater can be used as electronic donors in the denitrification. When the concentration of the organic is too low, carbon sources became the limiting factor [9, 10]. It can be seen from figure 4, when the influent COD/TN is greater than 6, the biofilm reactor can obtain good effect of denitrification.

4. Conclusions

The experiment used polyurethane as a media in the pre-denitrification biofilm reactor to investigate the effect of different operation conditions on synthetic wastewater treatment, the conclusions were as follows:

a) Polyurethane as the media in the pre-denitrification biofilm reactor is satisfactory according to the biofilm formation and removal performance.

b) When the biofilm reactor was operated at a hydraulic loading of $0.96\text{m}/\text{h}$ (HRT of 1.5h), an A/L of 8:1, a reflux ratio of 150%, the removal of COD, NH_4^+-N and TN achieved the optimum treatment efficiencies. The increasing of reflux ratio is helpful to improve the ability of denitrification at a certain range.

c) The COD and TN removal occurred mainly in anoxic zone and the NH_4^+-N removal occurred mainly in oxic zone. Nitrification in oxic zone directly affects denitrification in the anoxic zone.

d) The pre-denitrification biofilm reactor has a certain impact resistance of organic loading. When influent loading rate of COD, NH_4^+-N and TN are less than 6.42 , 0.71 and $0.58\text{kg}/(\text{m}^3\cdot\text{d})$, respectively, the removal of COD, NH_4^+-N and TN achieved the optimum treatment efficiencies. The influent concentration of TN affects the removal of TN greater than others.

e) When the influent COD/TN ratio is greater than 6, the biofilm reactor can achieve better effect of biological nitrogen removal.

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